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CORRELATION OF LABORATORY AND FIELD FRICTION MEASUREMENTS TO OPTIMIZE UTILIZATION OF BITUMINOUS SURFACE AGGREGATES

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16. Abstract

The basis of the current Utah Department of Transportation (UDOT) specification requirements for polish value of surfacing aggregates is not supported with a statistically adequate correlation. A statistically significant correlation is needed to prequalify surfacing aggregates for the anticipated frictional performance and allow optimal utilization of aggregate sources. Adequate prequalification of surfacing aggregates and correlation with the pavement frictional performance allows for suitable matching of the friction supplies to the pavement friction demands. The objective of this research is to develop a three-way correlation of measurements between the British Pendulum Tester (BPT) in the field, the BPT in the laboratory, and the lock-wheel skid trailer. Twelve pavement sections scheduled for resurfacing, each older than 8 years, were selected in Salt Lake, Sevier and Emery County consisting of open graded surface course (OGSC), hot mix asphalt (HMA), and stone matrix asphalt (SMA). Revised AASHTO laboratory polish value procedures were followed in order to reduce the variability inherent in the old procedures. Prior to performing skid testing, the laboratory pendulum was brought to the field for friction tests to correspond with the wheel path of the skid trailer. Given the findings of this study, the researchers recommend that UDOT engineers adopt the revised variability-reducing laboratory friction testing techniques. A statistically significant friction correlation (R^2 value of 0.81) between laboratory and field friction tests was found along with a statistically significant temperature correlation (R^2 value of 0.44).

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LIST OF ACRONYMS

AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ADT	Average Daily Traffic
ASTM	American Society for Testing and Materials
BPN	British Pendulum Number
BPT	British Pendulum Tester
CTM	Circular Texture Meter
DFT	Dynamic Friction Tester
FHWA	Federal Highway Administration
FN	Friction Number
HFSC	High Friction Surface Course
HMA	Hot Mix Asphalt
MP	Mile Post
MPD	Mean Profile Depth
MTD	Mean Texture Depth
OGSC	Open Graded Surface Course
PV	Polish Value
SMA	Stone Matrix Asphalt
SN	Skid Number
UDOT	Utah Department of Transportation
VPPL	Vehicle Passes Per Lane

EXECUTIVE SUMMARY

The basis of the current Utah Department of Transportation (UDOT) specification requirements for polish value of surfacing aggregates is not supported with a statistically adequate correlation. A statistically significant correlation is needed to prequalify surfacing aggregates for the anticipated frictional performance and allow optimal utilization of aggregate sources. Adequate prequalification of surfacing aggregates and correlation with the pavement frictional performance allows for suitable matching of the friction supplies to the pavement friction demands. The objective of this research is to develop a three-way correlation of measurements between the British Pendulum Tester (BPT) in the field, the BPT in the laboratory, and the lock-wheel skid trailer. Twelve pavement sections scheduled for resurfacing, each older than 8 years, were selected in Salt Lake, Sevier and Emery County consisting of open graded surface course (OGSC), hot mix asphalt (HMA), and stone matrix asphalt (SMA). Revised AASHTO laboratory polish value procedures were followed in order to reduce the variability inherent in the old procedures. Prior to performing skid testing, the laboratory pendulum was brought to the field for friction tests to correspond with the wheel path of the skid trailer. Given the findings of this study, the researchers recommend that UDOT engineers adopt the revised variability-reducing laboratory friction testing techniques. A statistically significant friction correlation (R^2 value of 0.81) between laboratory and field friction tests was found along with a statistically significant temperature correlation (R^2 value of 0.44).

1.0 INTRODUCTION

1.1 Problem Statement

When pavement friction demand is greater than pavement friction supply the results can be devastating and deadly. Because the risk associated with having low friction pavement is so high, pavement management stewards must be able to rely on and have confidence in data collection, analysis, and interpretation. But the variables that govern friction are multivariate, seasonal, weather dependent and overall very challenging to characterize (1). A reliable friction management plan, providing continuous, real-time, network-level data collection and analysis, is needed to adequately assess friction supply for roadways throughout a system and determine when maintenance or rehabilitation will be needed. Being able to predict friction supply over a pavement life cycle with multiple devices can ensure roads are safely rehabilitated in a timely and cost efficient manner. Utah Department of Transportation (UDOT) roadway managers faced with limited funding and the challenge of maintaining rapidly deteriorating roadways are seeking such a prediction model.

Pavement friction is one of the primary factors that controls skid resistance. The components that contribute to the friction of pavements have been extensively studied throughout the world over the past 60 years. Road friction between the tire and pavement surface is responsible for decelerating a vehicle on a roadway and supplying the friction needed during turning, accelerating or braking. Pavement friction is one of the most important factors in reducing the number of roadway departures, especially on wet pavements. A strong correlation exists between wet pavement with low friction and the probability of an accident (1, 2). Pavement friction includes both micro- and macrotexture and is related to surface texture. Pavement microtexture is defined as "a deviation of a pavement surface from a true planar surface with characteristic dimensions along the surface of less than 0.5 mm" while the pavement macrotexture is defined as "a deviation of 0.5 – 50 mm" (3, 4). Microtexture is a function of the surface texture of the aggregate particles and provides a texture that feels gritty to the touch that produces frictional resistance between the tire and pavement. Macrotexture is determined by the overall properties of the pavement surface and provides surface drainage channels for water to flow through as it is pressed between the tire and pavement. The contact area between the tire and pavement on wet surfaces is enhanced due to this ejection of water. Therefore, frictional resistance is also improved on wet surfaces with sufficient macrotexture. (5, 6).

Many field and laboratory testing devices are commonly used to measure and predict roadway surface friction. Examples of some of these are the Accelerated Polish Test, British Pendulum, Locked-Wheeled Skid Trailer, Micro Deval, Dynamic Friction Tester and others with many of the standards, theories and testing methods originating out of Europe. The main point of interest for most of the friction testing devices is to identify the quality of the road surface texture and quantify the friction value at the tire-pavement surface interface.

As discussed earlier, the overall road surface texture and properties of the aggregates used determine the frictional resistance. A strong link exists between friction and safety on a roadway (7). Based on available literature, a strong correlation between roadway friction and lane departures has been identified. Empirical evidence suggests that vehicle crashes are highly correlated to the amount of pavement friction available at the pavement–tire interface.

Even though friction has been exhaustively studied over the past few decades, new doors are being continually opened due to technological advances with measuring devices. These technologies lead to new research which continues to improve upon the ability to gather and analyze data at highway speeds throughout an entire network-level pavement system. With massive amounts of data being collected through technologies like scanning lasers and continuous friction measurement vehicles, there is a need to effectively analyze the data and look for clues to predict how friction is changing with time and traffic. There is also a constant need to sort through the data to look for patterns which can predict current and future friction supply in order to ensure that supply will keep up with the demand caused by the ever increasing traffic volumes. The rate at which data is being collected is exceeding the rate at which the data can be proficiently analyzed. Until tools are created to search, sort and scrutinize; the data will continue to pile up and expire on the shelf of the pavement management program before it can be utilized.

The desire for a friction prediction model has been an interminable quest for the pavement engineer (9). Pavement friction prediction models have been around for decades and so have the doubts about their accuracy, reliability, variability and repeatability. Many researchers conclude that their prediction equations do not take into account all possible variables and are only valid when the exact conditions are replicated (9). This problematic stipulation is because each new pavement is placed in a different manner than the one that preceded it. In other words, it is hard to replicate the conditions of the prediction equations. It appears that each state agency would require specifications tailored to that state's unique region(s) and climate(s). While other studies have attempted to develop correlations between field and laboratory friction measurements, the literature does not show that one has been conducted in an area like Utah, where a cold dry climate prevails.

This research project attempts to account for the high variability inherent to friction measurement and then manage it in a way that reduces the overall scatter in field and laboratory testing to ensure that a more accurate correlation can be achieved for regions like Utah. Previous research, as reported by Moon C. Won and Chien N. Fu, focused on identifying the controllable factors that contribute to the repeatability of the polish value (PV) test results and improving the PV test procedure (14). By following their recommendations, along with the revised AASHTO procedures, this research project focuses on reducing the variability in the laboratory and field measurements of friction testing in order to obtain correlations between the accelerated polish wheel, British Pendulum and lock-wheeled skid trailer.

The general understanding found in the literature is that there is an unacceptably high variability when correlating laboratory and field friction measurements (10, 11, 12, 13, 14). Some of the factors are uncontrollable such as: weather, seasonal changes, traffic, construction quality, etc. Research suggests there is frustration with the high variability and high inter-laboratory bias. For example, within a friction collection season, 30-point swings in skid number have been observed on the same section of pavement (8). The goal of this research is to incorporate the best practices of controlling variability and repeatability and refine the existing correlations between laboratory and field friction testing into a reliable prediction equation.

In 1996, UDOT commissioned a research study to help determine a lower limit value for both the field skid value and laboratory polish value. The researchers studied 32 chip seal pavement sites and conducted skid testing on each section and also performed laboratory polish testing on the aggregates from each section. A summary of the results from the study are shown in Figure 1. As can be seen, there does not appear to be a statistically adequate trend to the plot.

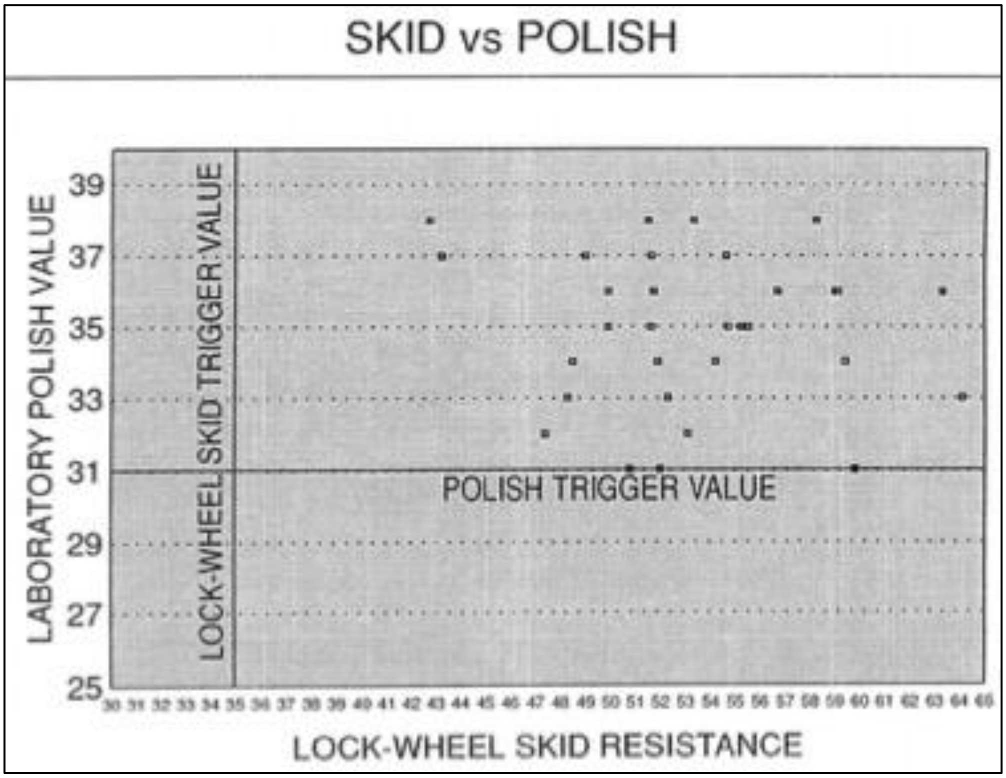

Figure 1 Plot of chip seal skid values and polish values from the 1996 UDOT report.

The purpose of this research is to perform testing similar to the 1996 research by comparing field friction measurements to laboratory friction measurements and evaluating how well the correlation between the two can predict the observed results. By using variability reducing laboratory and field testing techniques, the researchers hope to be able to provide a more defendable approach to selecting trigger values for both the skid trailer and laboratory polish test.

Although it is generally accepted that laboratory and field correlations do exist and have been established, the correlation focused on in this research has never been comprehensively quantified using revised laboratory and field-testing techniques on aggregates in Utah. A comprehensive treatment of this problem is presented that was developed using research conducted previously by the Texas Department of Transportation and Raba Kistner Inc. By adding a testing program to supplement and extend their earlier work, the researcher's goal is to produce statistically significant field and laboratory correlations for friction. Recommendations are made for the use of this information to establish friction guidelines. Appropriate use of this information by pavement managers can, in time, have a major impact on reducing accidents affected by low friction.

1.2 Objectives

The primary objectives of this research project are:

1. Perform laboratory polish value (PV) testing of surfacing aggregates and validate the British Pendulum Number (BPN) and PV correlation developed by TxDOT and INDOT.

2. Perform race-track locked-wheel skid testing and develop/validate the correlation between field BPN and locked-wheel skid number (SN). Selection of the pavement sections will consider the variations in geography and associated climatic conditions.

3. Monitor and evaluate the effects of cumulative traffic on BPN and SN measurements.

4. Develop a correlation between laboratory PV and field SN.

1.3 Outline of Report

This report contains five chapters. This chapter introduces the research, defines the problem statement, and identifies the research objectives and scope. Chapter 2 gives background information on friction testing and describes the research methods used in this report. Chapters 3 and 4 detail the procedures and results of this research, respectively. Chapter 5 provides conclusions and recommendations resulting from this research.

2.0 RESEARCH METHODS

2.1 Overview

This chapter details typical factors that affect pavement friction and also gives background information into UDOT's current friction management program. The research objectives and research potential for correlation are also discussed.

2.2 Background

UDOT has collected friction data at the network level on state routes for many years. Roads consisting of open graded surface course (OGSC), chip seal and micro-surfacing are required to have laboratory testing to determine the polish value. Current UDOT specifications indicate that a polish value equal to or greater than 31 is required on UDOT roads. The variability in the coefficient of friction for a pavement at terminal polish, as determined by ASTM E274, appears to be controlled primarily by pavement temperature and season of the year (16). Currently UDOT only corrects and normalizes the data for speed. Temperature measurements are not taken during testing.

The British Pendulum Tester (BPT) is capable of measuring the laboratory PV on a curved coupon and the BPN on a flat surface for both field and laboratory applications. The BPN is used as the common denominator to establish an indirect relationship between PV and SN (7).

The concept of a three-way relationship between SN, PV, and BPN tests is presented in Figure 2. The correlation requires striking aggregate coupons with a British pendulum in the laboratory and then with the same pendulum out in the field striking pavement sections consisting of aggregates of the same mineral composition. The field locations were then skid tested in the same locations as the pendulum strikes.

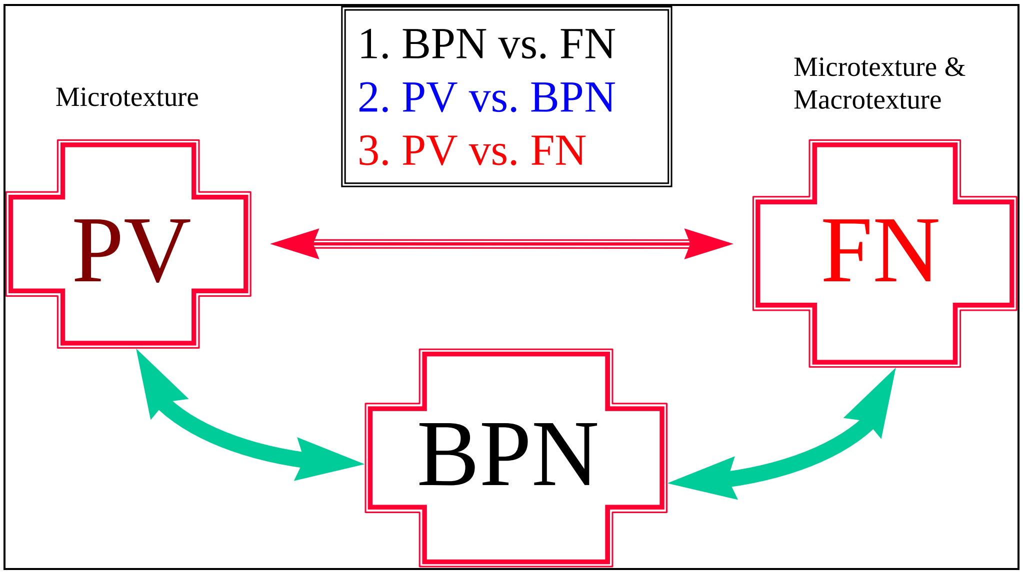

Figure 2 Relationship between polish value, friction number (FN) and British pendulum (14).

Field data collected at the twelve sites was used to develop correlations. Correlation No. 1 below was collected from the existing projects. Data used in correlation No. 2 included recent laboratory test results of selected aggregate sources. It is recognized by the researchers that the third correlation inherits the variability from the historical pavement and project information and lack of specific material properties for the aggregate used in pavement construction. Figure 3 represents the three tasks of objective 1 and their relationships visually.

1. Direct correlation between SN and BPN measurements collected in the field.
2. Direct correlation between BPN and polish value measurements collected in the laboratory; and,
3. Indirect correlation between SN and laboratory polish value.

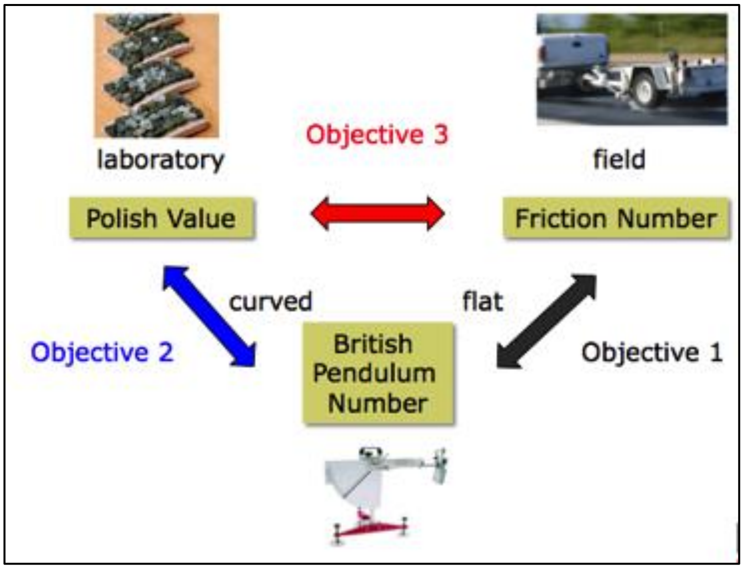

Figure 3 Research objectives for correlations.

To reduce the variability of field and laboratory data, improved field and laboratory test procedures were developed by a previous research team (14). Selection of aggregate sources and projects for testing and evaluation is based on the consistency of historical materials test history and service conditions of the existing pavements. Won and Fu's research team also established field and laboratory procedures to examine the effect of temperature on BPN and the effectiveness of polishing using current ASTM D 3319 and AASHTO T 289 procedures.

It has been previously reported by researchers that both field measured Skid Number (SN) and British Pendulum Number (BPN) shift toward lower values during the summer months, a reflection of higher tire temperature and a decrease in the exposed area at the micro level (13, 14, 15, 16). The general hypothesis, as presented by previous studies, is that in the summer there are prolonged periods of dry weather that allows the fine particles that are polished off the pavement surface to accumulate on the pavement surface resulting in a loss of micro- and macro-texture (14). This action together with contamination from vehicles, such as oil drippings and grease lead to lower skid resistance during late summer to fall. In winter, deicing salts cause the aggregate surfaces to rejuvenate and expose new mineral particles (13, 14). Due to heavy precipitation in the spring the fine grit is flushed out leaving coarser micro-texture on the aggregate surface. Rainfall also flushes out the drainage channels between the aggregate particles, thus increasing the macro-texture of the pavement. The coarser aggregate surface and increased macro-texture in turn leads to an increase in the skid resistance of the pavement in the spring and early summer. In addition, it is believed that the polishing action of the aggregate is reduced in winter as pavements remain wet for longer periods than in summer. In wetter periods the water film covering the pavement acts as a lubricant and reduces the polishing effect of vehicles on the surface aggregates (14).

Temperature of the tire rubber is another factor that affects the variation of measured skid number (SN). The mechanism involved in variation due to temperature change is attributed to hysteresis of the rubber tire. Hysteresis is the energy loss upon elastic recovery, in the form of heat, when the rubber tire is compressed as it slides over the pavement. It follows that at higher temperatures rubber becomes more flexible leading to more energy loss. Higher temperature thus leads to a decrease in the measured SN (14).

2.3 Testing Procedures

This research involved construction of laboratory sand control coupons, collection of aggregate test specimens, selection of field test sections, field and laboratory testing, and statistical analysis of pavement friction as described in the following sections.

2.3.1 Materials

Epoxy: In the past it has been observed by the researchers that coupons can experience warping due to epoxy shrinkage caused from differential curing of the hardening agent. The polyester resin used for this study followed the recommended ASTM formulation and met all the specifications as called out in ASTM D 3319.

Sand: Control coupons and high and low calibration coupons were constructed out of 20-30 Ottawa sand. The 20-30 Ottawa sand is predominantly a material passing the No. 20 sieve and retained on a No. 30 sieve. Ottawa sand was also used for the sand patch test to determine mean texture depth (MTD).

Aggregate: Samples of the aggregates used at each pavement site were sampled and tested which correspond to three pavement surface types: Hot Mix Asphalt (HMA), Stone Matrix Asphalt (SMA) and Open Graded Surface Course (OGSC).

2.4 Test Site Selection

Twelve existing pavement sections in UDOT Regions 2 and 4 consisting of OGSC, chip seal and SMA were selected that were displaying end of life conditions, based on vehicle passes per lane (VPPL) and are scheduled for resurfacing as soon as 2015.

The test sites selected for analysis were chosen based primarily on age and annual average daily traffic (AADT). In order to best match the field and laboratory testing it was decided that pavements near end of life would exhibit the most polished surfaces comparable to those of the laboratory accelerated polishing test, which represents a terminal condition. Five sites were selected in Region 2 and seven sites were selected in Region 4. The five sites in Region 2 consisted of OGSC which is predominately coarse aggregate. The OGSC material type ensures that the field tests were measuring properties of the coarse aggregates and not the properties of the fine sand and binder. For the seven sites in Region 4 all but one consisted of SMA with the last one consisting of a chip seal. The sites were selected on state routes that had a history of skid testing values over the last 10 years along with mix designs from when they were placed showing the percent of coarse aggregates and the quarry they came from.

2.4.1 Region 2 Sites

Site 1 was located in Tooele, Utah along State Route 36 between mile posts 57 and 58. At this location SR-36 consists of four lanes oriented in the north-south direction and received a 1-inch OGSC layer in 2005.
Site 2 was located in Magna, Utah along State Route 111 between mile posts 8 and 9. At this location SR-111 consists of five lanes including the median, oriented in the north-south direction and received a 1-inch OGSC layer in 2006.

Site 3 was located in West Valley, Utah along State Route 171 between mile posts 2 and 3. At this location SR-171 consists of three lanes including the median, oriented in the east-west direction and received a 1-inch OGSC layer in 2006.

Site 4 was located in Riverton, Utah along State Route 71 between mile posts 0 and 1. At this location SR-71 consists of five lanes including the median, oriented in the east-west direction and received a 1-inch OGSC layer in 2004.

Site 5 was located in Draper, Utah along State Route 89 between mile posts 364 and 365. At this location SR-89 consists of five lanes including the median oriented in the east-west direction and received a 1-inch OGSC layer in 2005.

2.4.2 Region 4 Sites

Site 6 was located near Scipio, Utah along south bound Interstate 15 between mile posts 188 and 190 as shown in Figure 4. At this location I-15 consists of a divided highway with two lanes in each direction oriented in the north-south direction and received a 3-inch SMA layer in August of 2007.

Site 7 was located near Sulphurdale, Utah along south bound Interstate 15 between mile posts 129 and 130. At this location I-15 consists of a divided highway with two lanes in each direction oriented in the north-south direction and received a 3-inch SMA layer in August of 2005.

Site 8 was located near Richfield, Utah along east bound Interstate 70 between mile posts 62 and 63. At this location I-70 consists of a divided highway with two lanes in each direction oriented in the east-west direction and received a 3-inch SMA layer in August of 2007 and then a ¼" chip seal in 2014.

Site 9 was located in Salina, Utah along north bound State Route 89 between mile posts 225 and 226. At this location SR-89 consists of three lanes, a median with one lane in each direction oriented in the north-south direction and received a 3-inch SMA layer in August of 2009.
Site 10 was located north of Redmond, Utah along north bound State Route 89 between mile posts 234 and 235. At this location SR-89 consists of three lanes, a median with one lane in each direction oriented in the north-south direction and received a 3-inch SMA layer in August of 2011.

Site 11 was located near Fremont Junction, Utah along east bound Interstate 70 between mile posts 87 and 88. At this location I-70 consists of a divided highway with two lanes in each direction oriented in the east-west direction and received a 3-inch SMA layer in August of 2011.

Site 12 was located west of Green River, Utah along east bound Interstate 70 between mile posts 153 and 154. At this location I-70 consists of a divided highway with two lanes in each direction oriented in the east-west direction and received a 3-inch SMA layer in August of 2008.

Figure 4 Coring along I-15 in Region 4 at site 6 near MP 188.

Table 1 lists each site location and surface type with date of placement.

Table 1 Location of Field Friction Test Sites

Site	Utah City	Route	Mile Post	Direction	Surface Type	Placement Year
1	Tooele	SR-36	57.8	SB	OGSC	2005
2	Magna	SR-111	8.8	SB	OGSC	2006
3	West Valley	SR-171	2.5	WB	OGSC	2006
4	Riverton	SR-71	0.5	WB	OGSC	2004
5	Draper	SR-89	364.5	NB	OGSC	2005
6	Scipio	I-15	189.8	SB	SMA	2007
7	Sulphurdale	I-15	129.5	SB	SMA	2005
8	Richfield	I-70	62.5	EB	Chip Seal	2014
9	Salina	SR-89	225.3	NB	SMA	2009
10	Redmond	SR-89	234.5	NB	SMA	2011
11	Fremont Junct.	I-70	87.5	EB	SMA	2011
12	Green River	I-70	153.5	EB	SMA	2008

2.5 Summary

The 12 test sites selected for analysis were chosen based primarily on age and AADT. In order to best match the field and laboratory testing it was decided that pavements near end of life would exhibit the most representative surfaces comparable to those of the laboratory accelerated polishing test, which represents a terminal condition. Prior to fieldwork the sites were visited and walked in order to locate representative sections of pavement free of crack sealant and other obvious pavement distresses. At each site, four locations were selected for testing and each test location was divided into three spots for BPN measurements as shown in Figures 5 and 6. A total of 46 BPN test locations were selected from the twelve sites, and survey-grade nails were installed in the pavement surface so that repeat testing could be performed at the same locations in the fall.

3.0 DATA COLLECTION

3.1 Overview

This chapter includes information explaining how and why the friction data was collected for the research and where the data is available. Pictures of the different tasks are shown along with visuals describing testing protocols. Each testing method used during data collection is described in detail.

3.2 Field and Laboratory Testing

Field-testing for this research involves a two-phased collection period which includes two site visits in order to take into account the seasonal and temperature variations that influence pavement friction.

Skid number and ambient, pavement and tire temperature testing was performed during both visits. Laboratory testing of the PV was measured only one time because the micro friction properties of the aggregate remain constant. Ideally, the SN would be measured in the spring and fall in order to collect values representative of average annual conditions (17). Summer testing tends to decrease the SN due to higher temperatures and grime and debris accumulation on the road surface (15)

Discussions of procedures utilized to collect both the primary and secondary data required in this research are provided in the following subsections.

3.2.1 Primary Data Collection

Primary data included laboratory PV, BPN, SN, mean texture depth, temperatures (pavement, ambient, tire), average daily traffic (ADT), percent trucks, and pavement age.

At each of the twelve sites, four locations along the outside lane, in the inside wheel-path were selected for BPN testing as shown in Figures 5 and 6. Locations were selected in areas considered most representative of the roadway and free from obvious cracking and surface defects. Each location was spray painted with a 2’ x 4’ box and divided in half. Each box was first swept clean with a brush and then the BPN was measured in the center of each half making sure the strike path was covering a representative area of pavement. A third location in the middle of the wheel path directly below the center of the box was selected for the third BPN test at each of the four locations at each site. The sand patch test was then performed in the dry center of the left side box. Each site was tested in 4 locations and each location was tested at three spots. Spot A and B were in the wheel path and Spot C was in the middle of the lane between wheel paths. BPN was measured along the pavement surface in general accordance with AASHTO T-278 (Standard Method of Test for Surface Frictional Properties Using the British Pendulum Tester) at each of the 3 test spots in each of the four sections at each of the 12 sites, for a total of 144 BPN measurements.

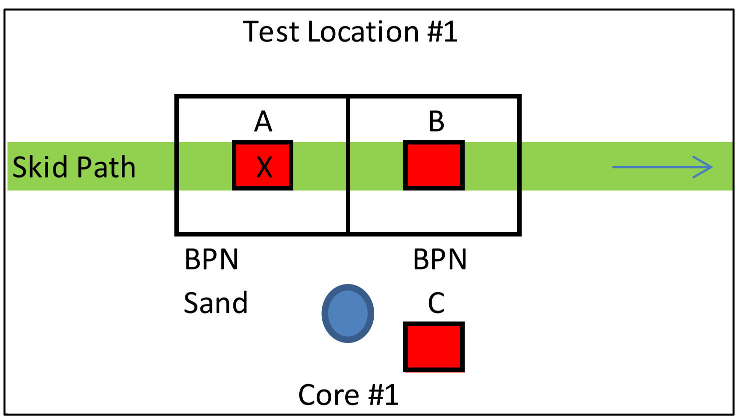

Figure 5 Testing protocols for each location.

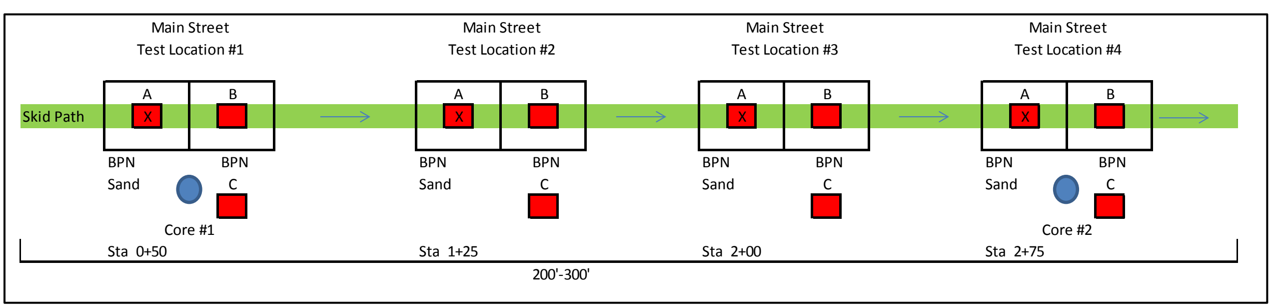

Figure 6 Testing protocols for each site.

3.2.1.1 British Pendulum Tester - BPT

A British Pendulum Tester (BPT) was used to determine the pavement friction at the race-track test locations. The test locations were chosen in areas where the least grade changes and surface defects and inconsistencies were observed. The BPT measures the relative friction between the pavement surface and the rubber slider. The slider is loaded by a tension spring that is calibrated at 2550± 50 grams. A 1¼ inch rubber slider as specified by ASTM E 303 (Standard Test Method for Measuring Surface Frictional Properties Using the British Pendulum Tester) was used for the friction measurements. Along the skid path of each race-track test location, two BPN friction measurements were obtained approximately 3 feet apart using the 1 ¼ inch ASTM slider. Any debris present on the pavement surface at the contact points was brushed away prior to wetting to ensure valid readings. The pendulum was leveled using a bubble level and then adjusted to create a 3 ⅞-inch strike path in the outside lane in the driver side wheel path parallel to the center line, as shown in Figures 7 and 18. The pendulum was dropped and the residual BPN was recorded, which is the value reached with four constant, consecutive results.

Figure 7 Measuring surface friction with a British pendulum tester.

3.2.1.2 Polish Value - PV

The PV was measured in the laboratory, as shown in Figure 8, following ASTM E 303, AASHTO T-278 (Standard Method of Test for Accelerated Polishing of Aggregates Using the British Wheel) and AASHTO T-279. Initial and terminal polish values were measured.

Researchers fabricated aggregate coupons consisting of aggregate from the same supplier as were provided when the existing pavements were constructed by sampling from aggregate stock piles that were used during construction. The samples were prepared in a way to avoid bias by randomly selecting aggregate particles to be included in the coupon fabrication (18).

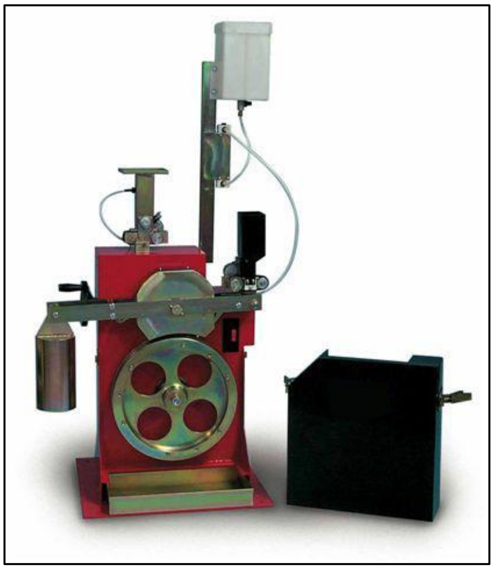

Figure 8 Accelerated polish machine.

3.2.1.3 Skid Number - SN

The SN was measured following ASTM E 274 (Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire). The pavement friction was tested using a lock-wheeled skid trailer, shown in Figure 9, during three different months July 2014, November 2014, and June 2015. A race-track method was used to collect multiple SN's at selected locations. The race-track method uses repetitive wetting and scrubbing, as friction testing is continued on the same skid path, to minimize the seasonal and operator variability of the standard procedure, and to gain greater consistency (14).

Prior to friction testing the skid trailer was calibrated and checked for cold inflation pressure and tread depth. Data were collected in a race track style method by returning to the previous skid location and testing until four consecutive passes, within 2 points of each other, were obtained. The race-track procedure requires gathering data from the initial conditioning runs and subsequent test runs until a set of four SN's that are within a two-point spread is obtained. In some cases up to ten passes were required to sufficiently clean the surface of debris/grime and settle on an SN.

Figure 9 UDOT's friction measuring skid trailer.

The SN value recorded was the average of the four consecutive tests meeting the 2-point criterion. The skid trailer was set to manual mode and controlled by the driver. The skid path length was approximately 80 feet in length and began at station 0+00 of the test sections. The race track test locations were chosen in areas where the least grade changes and surface defects and inconsistencies were observed. For both the network and race-track test procedures the skid trailer was able to maintain the test speed of 40±2 mph with few exceptions. It was possible to obtain four SN’s within a two point spread at most race-track test locations.

3.2.1.4 Temperature

Pavement and tire temperature measurements were taken using an infrared non-contact thermometer. A vehicle controlled temperature meter was used to measure the ambient air temperatures.

3.2.1.5 Strike Path Length

In order to determine the proper BPN travel distance on a pavement surface in the field for the rubber slider on the BPN, a correlation between curved coupons and flat coupons had to first be established. In order to accomplish this, a modified 7 inch curved coupon, shown in Figure 10, from the polish machine was heated in the oven and then flattened strait. The length to achieve similar BPN values on both the curved and flat coupon was determined by adjusting the strike path on the flat coupon until it was identical to the curved. It was found after that a 3 ⅞-inch strike path on a flat polished surface was equivalent to a 3 inch strike path on a curved polished coupon. All flat field measurements were conducted using a 3 ⅞-inch strike path for the 1 ¼ inch rubber slider to eliminate variables that could have been incorporated if a 3 inch rubber slider pad had been used in the field.

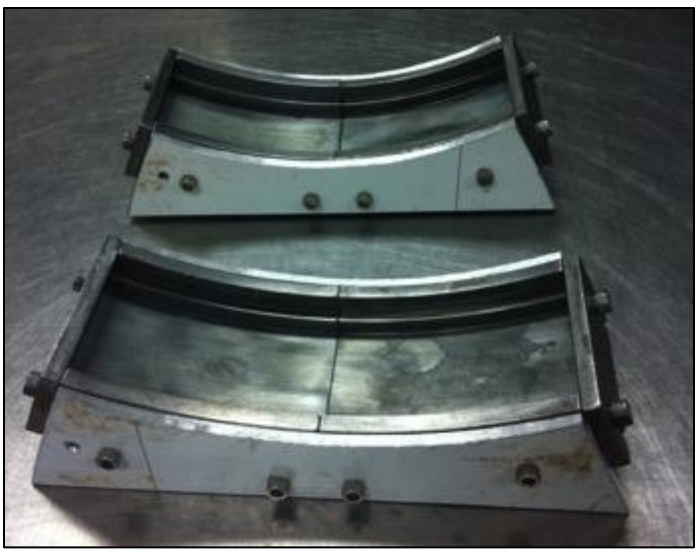

Figure 10 Custom molds for creating large coupons to flatten.

Figure 11 Measured ruler marked for travel path of 3 7/8 inches.

3.2.1.6 Mean Texture Depth

Mean texture depth (MTD) was measured using the sand patch test by following ASTM E 965 (Standard Test Method for Measuring Pavement Macrotexture Depth Using a Volumetric Technique) at each of the locations marked “A”, as shown in Figure 6, for all test sites. Each test location was cleared of debris by sweeping the road surface with a small hard bristle brush. A known volume of Ottawa sand was then poured onto the road surface to form a cone. The sand was spread with a spreading disc to form a circular patch and all the surface depressions between the aggregate peaks were filled to level. The diameter of the circle was then measured at four different angles rotating 45 degrees between each measurement as shown in Figure 12. The sand was used only once and discarded after each test. Air and pavement surface temperatures at the time of testing were also collected.

Figure 12 Measuring the mean texture depth using sand patch method.

3.2.2 Additional Primary Data Collection

After testing the 12 sites in 2014 and while the researchers were preparing for a second round of testing in 2015, an opportunity arose to borrow the latest equipment to measure pavement texture and friction from the Federal Highway Administration (FHWA). Through the FHWA equipment loan program state transportation departments and partnering research institutions can request equipment loans to become acquainted with the devices or to use them as part of a pavement friction or texture testing study. Two devices, the Circular Texture Meter and the Dynamic Friction Tester were requested by UDOT from the FHWA. The devices were received in Utah for a two-month period and then shipped back. During this time, an instructor from Penn State was flown in to provide a day-long workshop on how to operate the devices. The entire program represents an approximate $100,000 benefit to UDOT and provides great benefit to this research.

3.2.2.1Dynamic Friction Tester

The Dynamic Friction Tester (DFT) is a more current method for measuring in-situ pavement friction. The DFT is a portable instrument with three rubber pads, similar to the British Pendulum, that are mounted to the bottom of a rotating disc. The spinning disc is brought up to highway speeds and then dropped onto the pavement surface. The DFT continuously measures friction as it slows down gradually due to the friction between the sliders and the test surface. Similar to the lock wheeled skid test and British Pendulum, water is sprayed onto the surface prior to testing with the DFT. The coefficient of friction is calculated by dividing the continuously measured torque force by the weight of the spinning disc.

One advantage of the DFT is that it continuously measures friction at all speeds from approximately 0 mph to 65 mph, compared to the British Pendulum which can only measure speed at which gravity pulls the pendulum arm down (approximately 8 mph). Research has indicated that correlations between the skid trailer, which operates at 40 mph and DFT are higher than correlations with a British Pendulum. Another advantage is that the footprint of the DFT, shown in Figures 13, 14 and 15, is the same size as the testing footprint of the Circular Texture Meter (CTM). Combining the DFT and CTM values together allows for the calculation of an International Friction Index number, a value used to harmonize friction measurements between a wide variety of testing devices around the world.

The DFT tests were taken in the same locations as the racetrack skid tests and British Pendulum tests. Four tests were taken at each site for a total of 44 tests (one location had been paved over and no longer available). All tests were run according to ASTM E 1911-98 (Std Test Method for Measuring Paved Surface Frictional Properties Using the Dynamic Friction Tester).

Figure 13 DFT testing along side British pendulm.

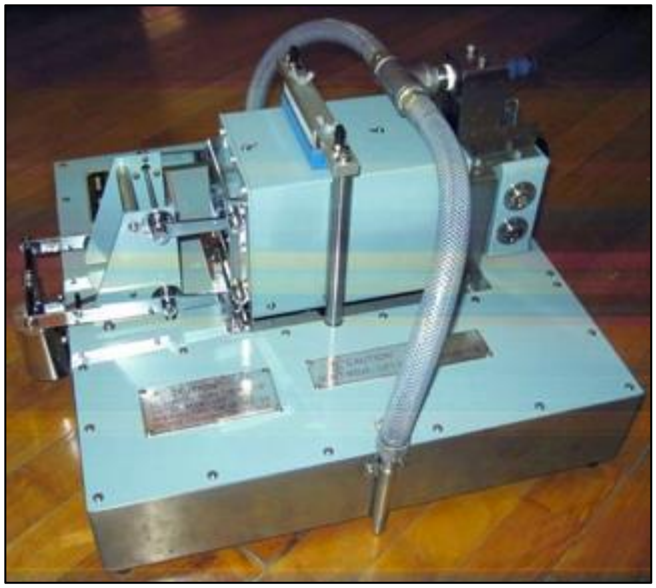

Figure 14 Dynamic friction tesing device.

Figure 15 Underside of DFT with three rubber pads attached to rotating disk.

3.2.2.2 Circular Texture Meter

Another method for measuring texture and the surface profile of the pavement is with a Circular Texture Meter (CTM) The CTM uses a laser to scan the surface of pavements in a circular pattern to calculate a mean profile depth (MPD). The CTM, as shown in Figure 16, is a stationary test and takes approximately 30 seconds to run. The footprint of the laser scan is the same size and shape as that of the DFT. The CTM tests were taken in the same locations as the racetrack skid tests, DFT, and British Pendulum tests. Four tests were taken at each site for a total of 44 tests. All tests were run according to ASTM E 2157 (The Standard Test Method for Measuring Pavement Macrotexture Properties Using the Circular Track Meter).

Figure 16 Circular texture meter device.

3.2.3 Secondary Data Collection

Secondary data included, ADT, pavement age, mix design properties (including gradation, oil content, PG grade, and specific gravity), percent trucks, placement contractor and core information. For this research, two 6-in.-diameter cores were drilled in the pavement layers at each test site as shown in Figure 17. Coring allowed a direct measurement of the asphalt OGSC layer thickness. After the core was removed, cold patch was compacted into the hole to fill the void.

Figure 17 Coring operation between wheel paths, adjacent to BPN testing.

3.3 Summary

Overall, the primary and secondary data collection process involved a vast array of friction measurement devices. Through the FHWA loan program, additional devices that were not included on the original scope of work were utilized to advance the research findings.

4.0 DATA EVALUATION

4.1 Overview

This chapter includes information on how and why the data were evaluated. Figures showing the correlations between each friction measuring device are presented along with analysis and R^2 values for statistical confidence. The equations developed using the findings of this research can be used to estimate skid values when a British pendulum is available and vice versa.

4.2 Data Analysis

Following data collection and reduction, the results of BPN and skid values were investigated for correlations. Several other factors of interest were also investigated for correlations which include, pavement temperature, tire temperature, ambient temperature, PV, ADT, pavement age, and mean texture depth. Figure 18 shows the BPT placement location in the inside wheel path of the outside lane.

Figure 18 Location of BPT in left wheel path of outside lane.

4.2.1 Data Analysis for Objective 1

The following sections present the results of this research in two phases. The first phase of testing was conducted in 2014 and the second phase was conducted in 2015. Each phase consisted of the same testing procedures. These results are specific to the pavement surface characteristics and climatic conditions present along the project corridor.

The following figures present the data from both the 3-inch wide rubber pad and the 1 ¼ inch wide rubber pad. The purpose of using two different sizes of slider pad was to find which one performed better in order to reduce the variability in the testing. It appears that the 3-inch slider pad provides a better correlation. The 1¼-inch pad had an R^2 value of 0.75 while the 3-inch pad had a slightly better R^2 value of 0.81.

The correlation between the race-track SN's and BPN's are shown in Figures 19 and 20. These correlations are consistent with previous research studies (14) and our own experience in pavement friction testing and evaluation. Each site was tested in 4 locations and each location was tested at three spots. Twelve tests were performed at each test site. Test locations are described in section 3.2.1.

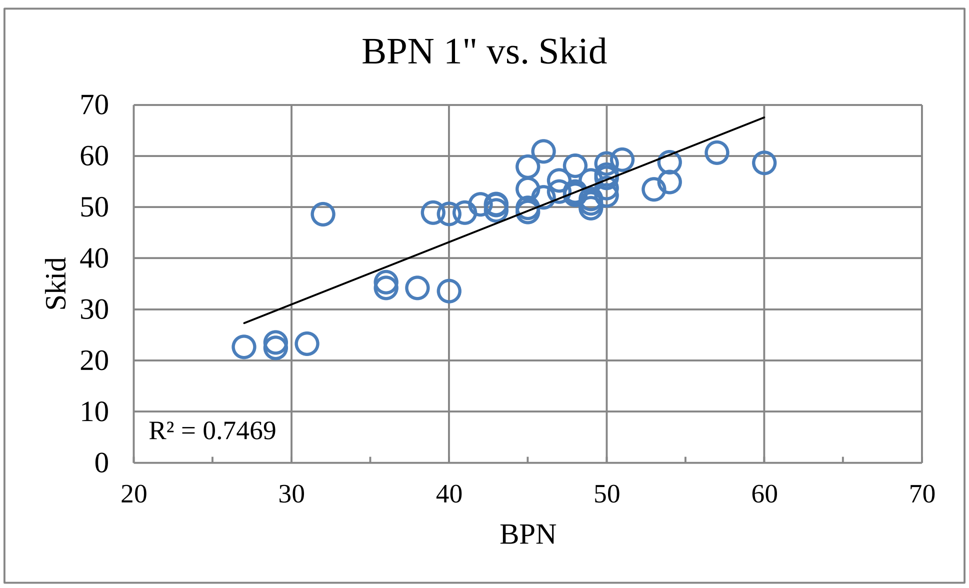

Figure 19 Correlation for 1.25 inch slider pad.

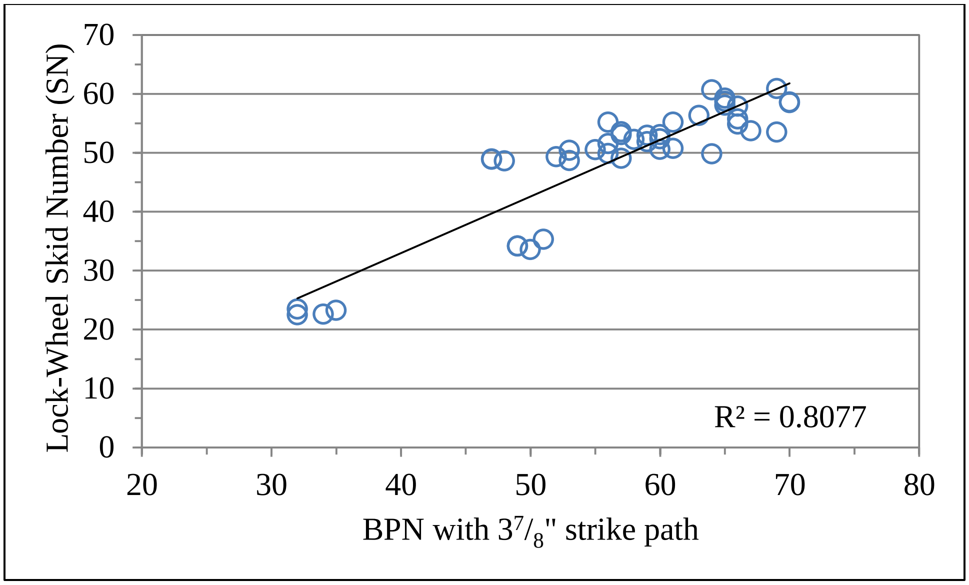

Figure 20 Correlation for 3 inch slider pad

The best correlation obtained was found with the 3-inch rubber pad. However, the correlation that best fits the data to correlate with the laboratory was the 1 ¼-inch pad along with a 3⅞-inch strike path. Therefore, the 1 ¼-inch pad was used in establishing the correlation to complete Objective 1 between the British Pendulum and the skid trailer. The equation to predict skid values based on pendulum values is shown in Figure 21

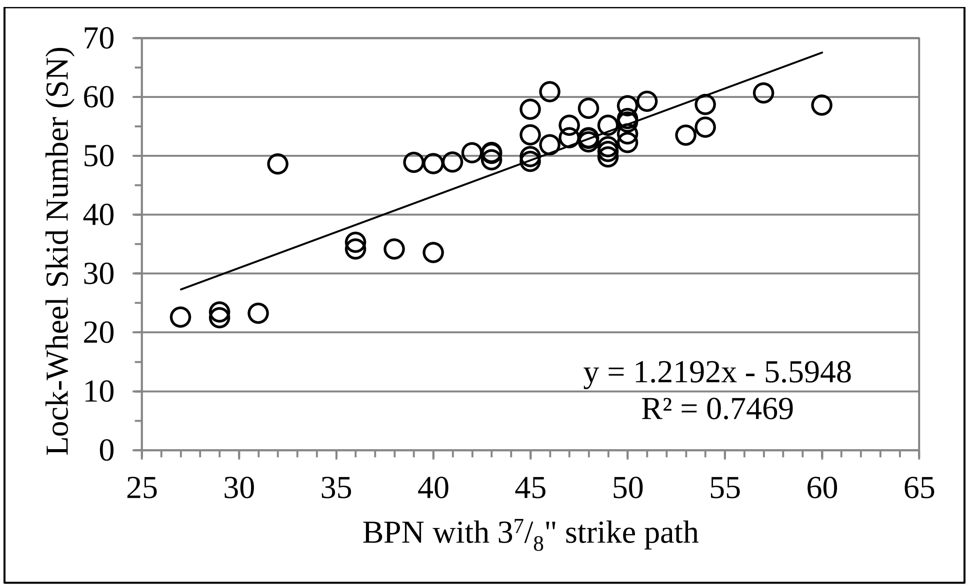

Figure 21 R^2 correlation equation to relate british pendulum to skid value.

4.2.2 Data Analysis of Traffic and Skid Values

The results of comparing the SN to ADT in Figure 22 show the opposite effect of what was predicted. It appears in Figure 22 that as traffic increases the field friction also increases. In this case the surface of the OGSC could be raveling and stripping out of the surface and leaving behind deep pockets of texture, heavy with macro-texture, which can increase friction.

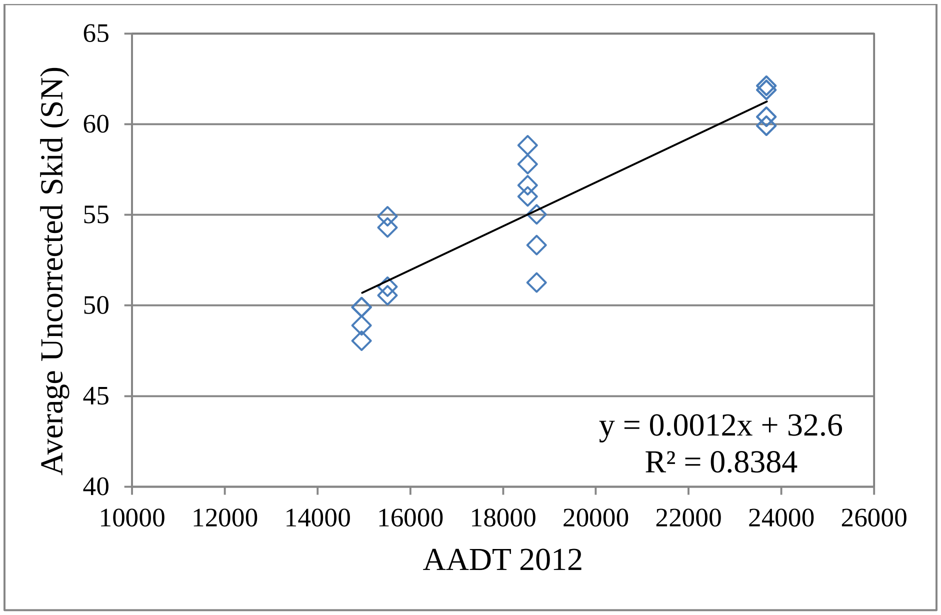

Figure 22 Average daily traffic versus SN.

4.2.3 Data Analysis for Objective 2

When comparing the accelerated polish test value (PV) to the skid number (SN) as shown in Figure 23 the R^2 is 0.62. The correlation between PV and field BPN is not as strong as the correlations between SN and BPN, and PV and BPN. However, this may be explained by the fact that the polish test represents end of life conditions and the British pendulum test conducted on the road surface is taken at an unknown point in time along the polish deterioration curve. For this reason an R^2 value of 0.62 is actually quite good.

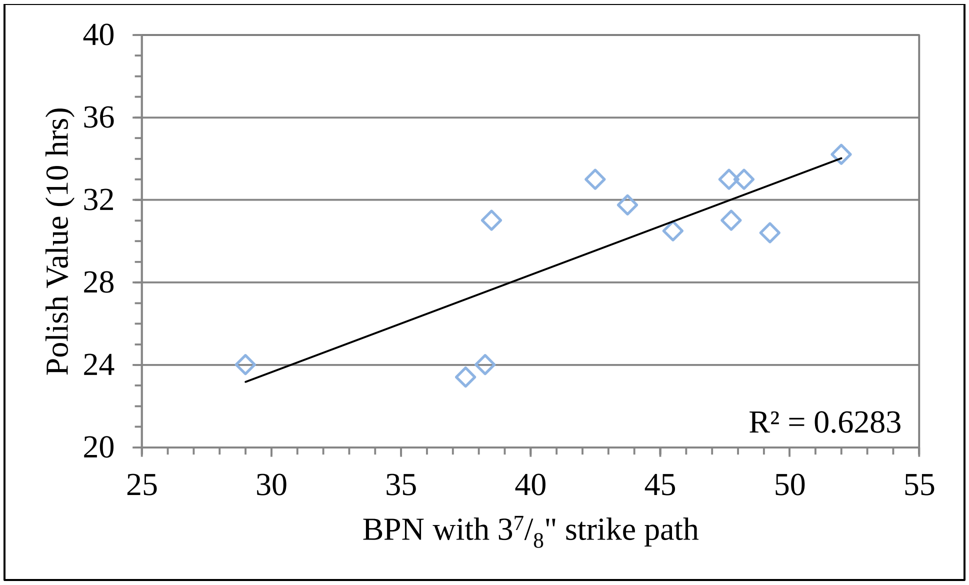

Figure 23 Average laboratory polish value versus field BPN.

4.2.4 Data Analysis of Temperature and Skid

A plot of temperature and SN from Region 2 in Figure 24 indicates a strong visual correlation between pavement temperature and SN. The R^2 value of 0.44 indicates that temperature accounts for less than half of the reduction in the SN. The correlations between temperature and skid value in both Regions 2 and 4 are not as strong as the correlations between temperature and skid in Region 2 alone. However, this may be explained by the fact that each region has a unique climate and when they are combined together the diversity between the two climate zones is masked. Further effort into the correlation between temperature and SN is suggested for future research. The findings are in line with the fact that as temperatures increase, the rubber becomes softer which in turn reduces the friction numbers.

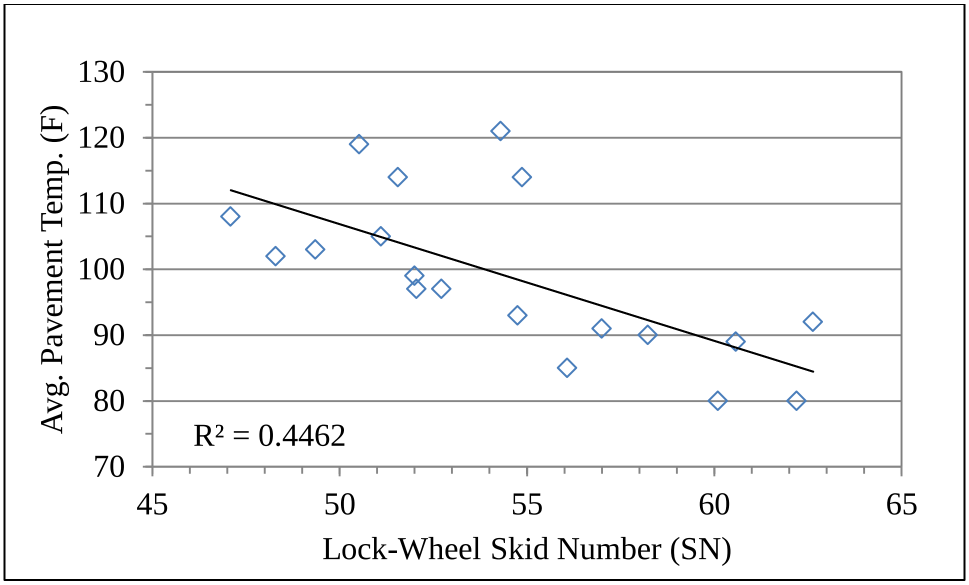

Figure 24 Region 2 pavement temperatures versus SN.

The following figures combine both the Region 2 and Region 4 data to create a picture of the statewide trends seen within pavement friction testing. Figure 25 displays a trend with BPN and temperature which indicates that as the temperature increases the friction value of the Pendulum decreases. This finding is consistent with previous research covered in the literature for this research. This same downward trend is not only found with the skid trailer but is also found with the BPT, Figure 25 shows that as pavement temperatures increase the pendulum values decrease.

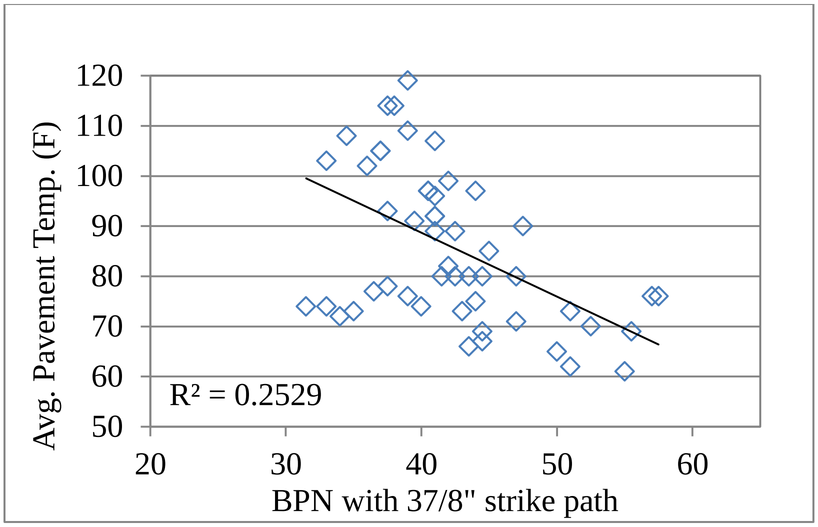

Figure 25 Region 2 and 4 pavement temperature versus BPN.

The downward trend of the friction value as temperatures increase not only applies to Region 2 but also the skid trailer in Region 4 as seen in Figure 26, the R^2 value is not as high as for Region 2 but the trend still holds for the skid trailer.

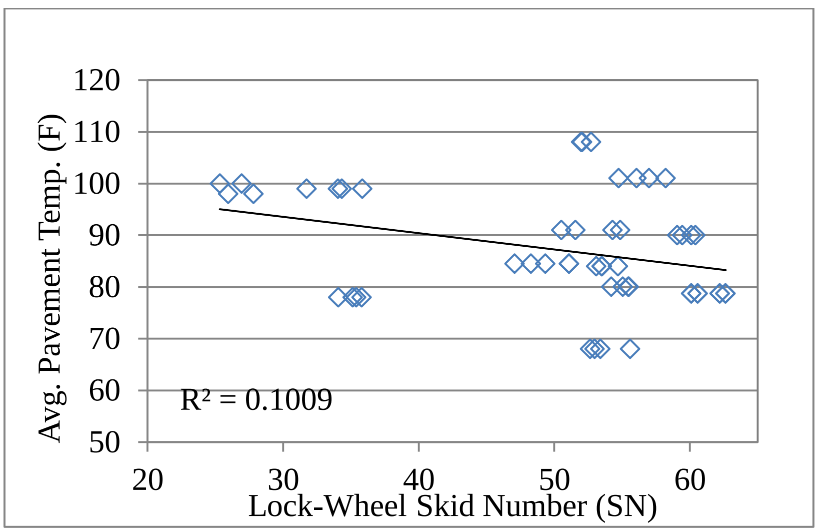

Figure 26 Region 2 and 4 pavement temperature versus SN.

4.2.5 Data Analysis for Objective 3

The correlation between the laboratory polish value and the skid trailer had the best correlation out of the three objectives with an R^2 value of 0.81 as shown in Figure 27.

The field data collection and laboratory performance data indicate that a correlation can be successfully identified between field BPN and SN. For the first objective, between the skid trailer and the British Pendulum in the field, the plots and corresponding correlation equations are shown in Figure 27. Both the 1 ¼-inch and 3-inch rubber pad were used at each location with the 3-inch pad producing a better correlation as shown in Figure 28. The correlation for the 1¼-inch rubber pad and 3 7/8-inch travel path had an R^2 value of 0.75 with the following equation:

$$\boldsymbol{Predicted\ Skid\ Value\ (SN_{40R}) = 1.22 \cdot (BPN_{1.25"}) - 5.6} \qquad \textbf{\textit{Eqn. 1}}$$

SN_{40R} = measured skid number with a ribbed tire at 40 mph.

$BPN_{1.25"} = \ Average\ British\ Pendulum\ value\ after\ 4\ strikes\ with\ 1\frac{1}{4}\ inch\ slider\ pad.$

The correlation equation for a 3 inch pad width and 5 inch travel path had an R^2 value of 0.81 and consists of the following equation:

$$\boldsymbol{Predicted\ Skid\ Value\ (SN_{40R}) = 0.96 \cdot (BPN_{3"}) - 5.5} \qquad \textbf{\textit{Eqn. 2}}$$

SN_{40R} = measured skid number with a ribbed tire at 40 mph.

$BPN_{3"} = \ Average\ British\ Pendulum\ value\ after\ 4\ strikes\ with\ 3\ inch\ slider\ pad.$

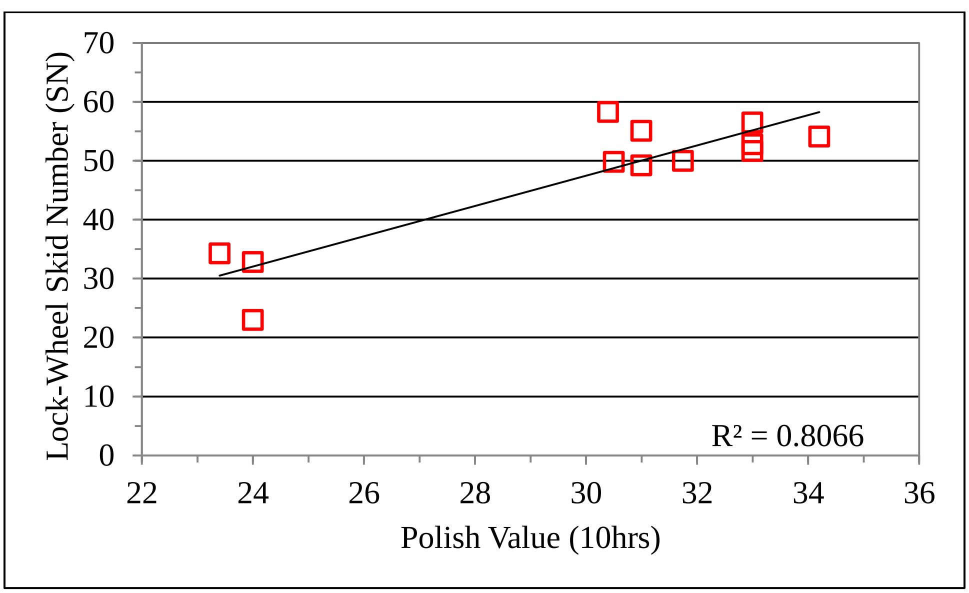

Figure 27 Lock wheel skid value versus laboratory polish value.

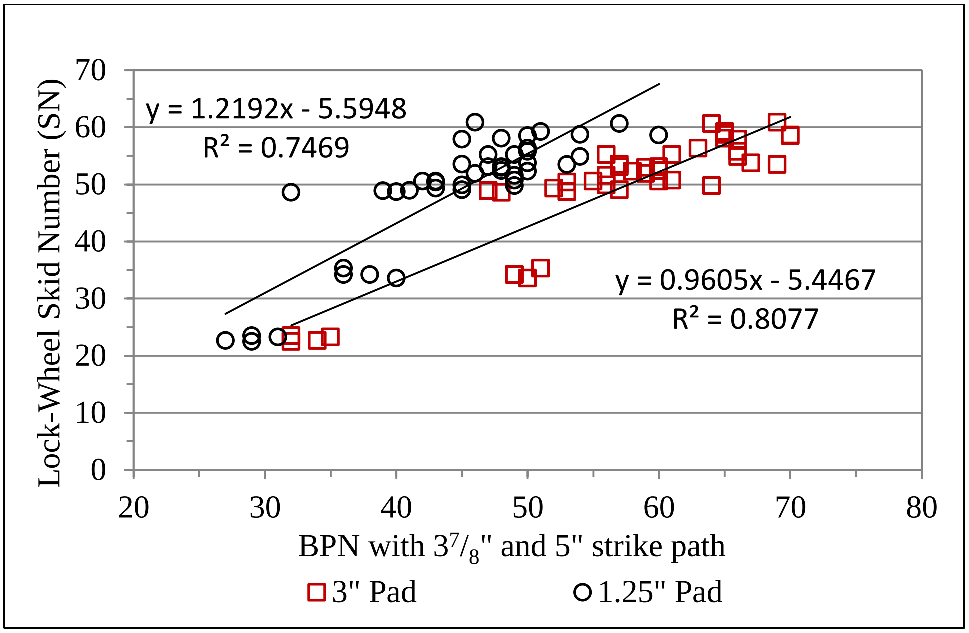

Figure 28 Correlation equations for both sizes of rubber pad to skid trailer.

4.2.6 Data Analysis for DFT and CTM

In addition to the correlations obtained from the three task of Objective 1, correlations were also made comparing the CTM and DFT to skid friction and accelerated polish tests. In both instances the R^2 value for the correlations was higher when using the new equipment. The following plots, in Figures 29 through Figure 34, show the correlations using the new equipment.

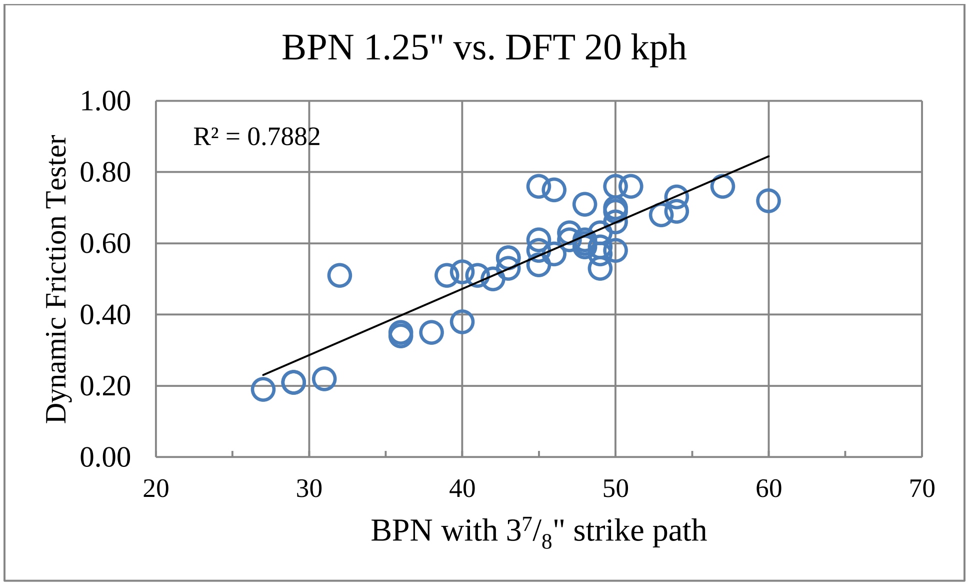

Figure 29 Comparison between the DFT and BPT with 1.25" pad.

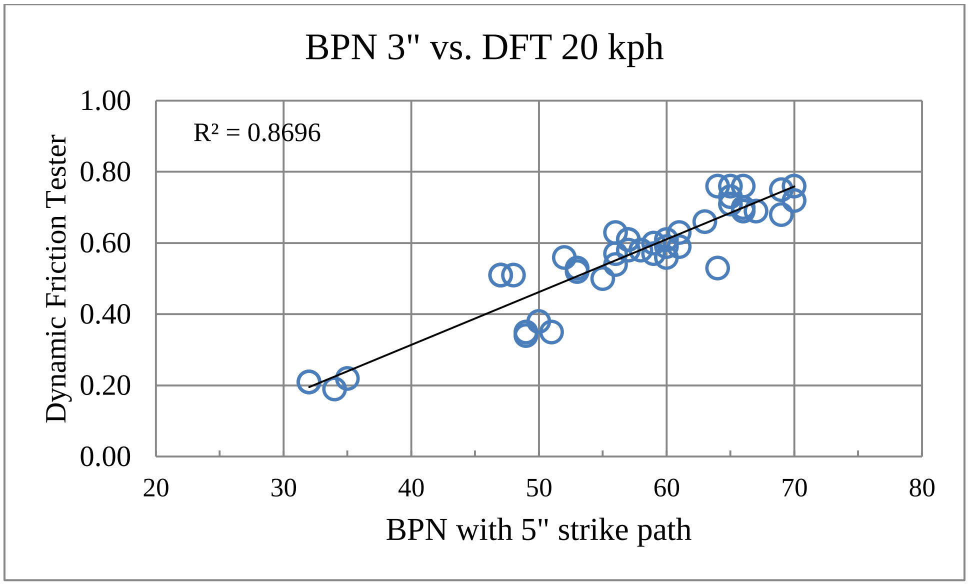

Figure 30 Comparison between the DFT and BPT with 3" pad.

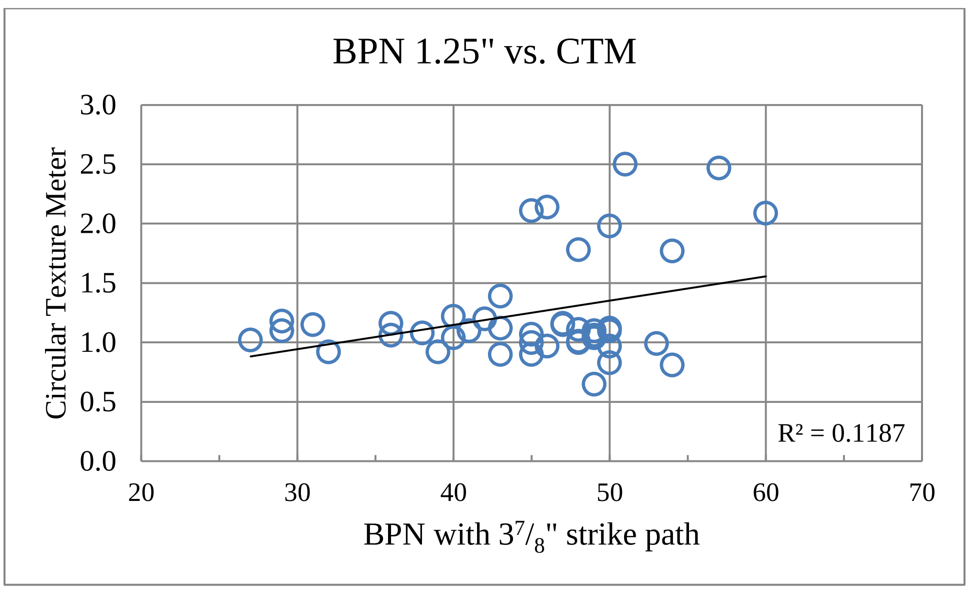

Figure 31 Comparison of the circular texture meter and 1.25 inch BPT.

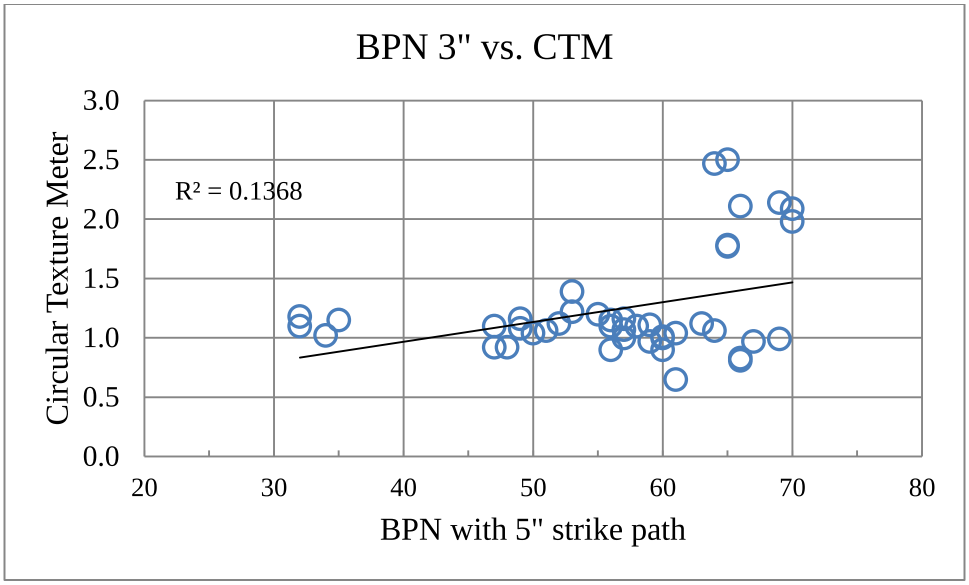

Figure 32 Comparison of the circular texture meter and 3 inch BPT.

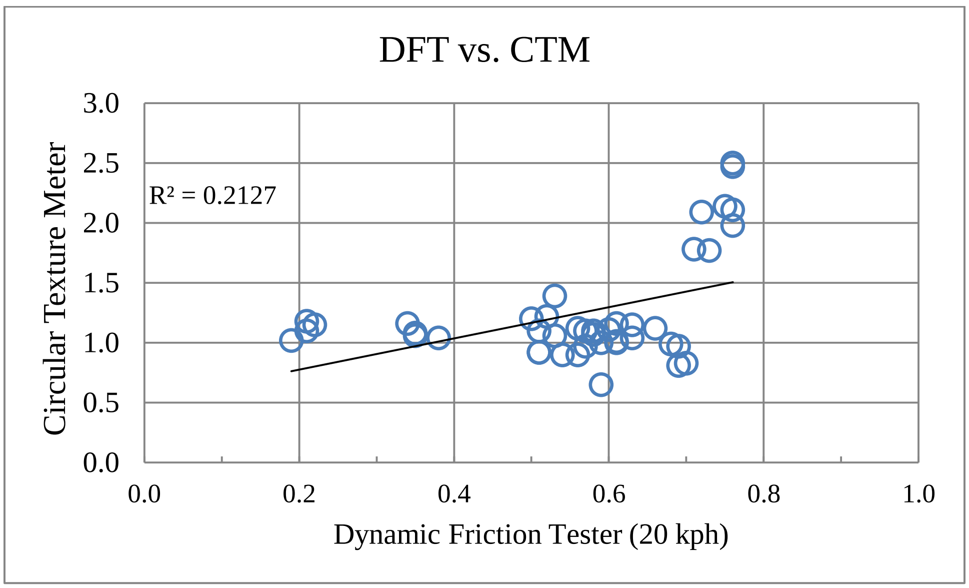

Figure 33 Comparison of the circular texture meter and dynamic friciton tester.

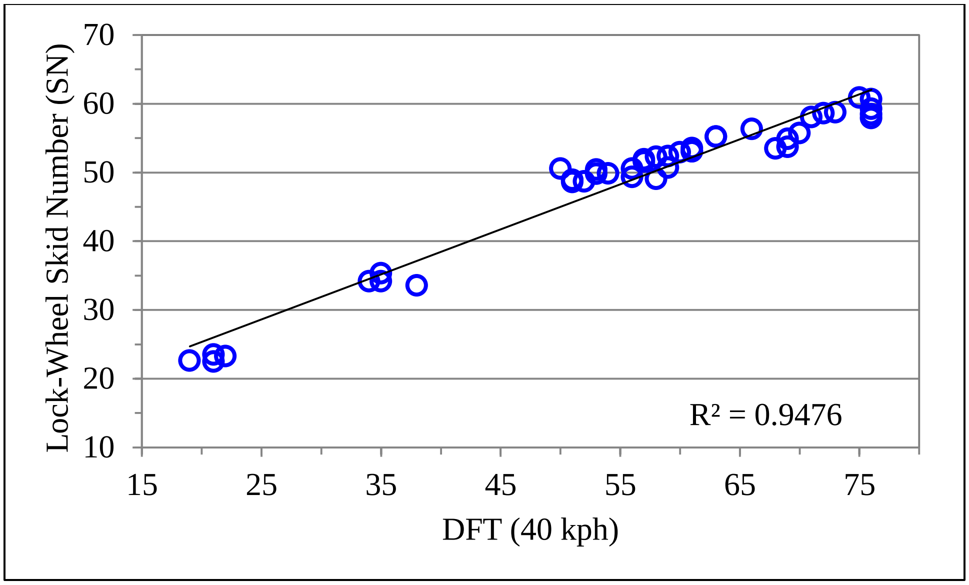

Figure 34 Comparison of skid trailer to the DFT at 40 kph.

4.3 Summary

Overall, relatively high R^2 values were obtained for each of the three correlation objectives. Additionally, when using the equipment provided through FWHA loan program (CTM and DFT) R^2 values increased by as much as 20%.

5.0 CONCLUSIONS

5.1 Summary

This chapter summarizes the research findings and provides recommendations and conclusions.

The basis of the current Utah Department of Transportation (UDOT) specification requirements for polish value of surfacing aggregates is not supported with a statistically adequate correlation. A statistically significant correlation would guide adequate prequalification of surfacing aggregates for the anticipated frictional performance and allow optimal utilization of available bituminous aggregate sources. Adequate prequalification of surfacing aggregates and correlation with the pavement frictional performance allows for suitable matching of the friction supplies to the pavement friction demands. The objective of this research is to develop a three-way correlation between the BPT in the field, the BPT in the laboratory, and the lock-wheeled skid trailer.

This research project identified 12 sites consisting of nine aggregate sources for field evaluations of SN and BPN. The pavements were primarily near end of life and consisted of OGSC, SMA and chipseal. The five existing pavement sections located in Region 2 in Salt Lake were scheduled for resurfacing in the coming year. Of the seven pavement sections in Region 4 only four are scheduled to be resurfaced in the next two years.

The purpose of this research is to compare the field and laboratory friction measuring devices and evaluate how well the correlation can predict the observed results. Field and laboratory data included laboratory PV, BPN, SN, mean texture depth, temperature, ADT, percent trucks, and pavement age. At the conclusion of this study 149 BPN tests had been conducted and 46 SN race track style skid tests had been performed. Revised laboratory polish value procedures (including coupon flattening, control coupons usage and random aggregate placement techniques) were followed in order to eliminate inherent variability and increase repeatability. Field friction tests using the same laboratory pendulum were conducted prior to performing race-track type skid testing at each site.

The correlation for objective 1 between SN and BPN was found to be reasonably good with an R^2 value of 0.75. The correlation between SN and pavement temperature in Region 2 had a lower R^2 value of 0.44, while the combined Region 2 and 4 R^2 value was 0.10. The drastic change in values may be attributed to the rainy and colder temperatures that occurred on the first day of testing in Region 4. It should be noted that both the SN and BPN measurements are affected by temperature. The correlation between SN and pavement temperature in Region 2 was reasonably high with an R^2 value of 0.44. Other research studies have shown that the temperature effect on SN can vary from 1.5 to 3 skid numbers per 10 degrees F change in temperature (8).

5.2 Findings

As part of this study there was an effort to measure the surface texture using the sand patch method to calculate mean texture depth. The method and results of the testing were unable to provide a basis for qualitative interpretation. Additional testing data should be collected in the future and added to the current data set to see if a correlation can be found.

5.2.1 Findings Item 1

A significant friction correlation (R^2 value of .81) between laboratory and field friction tests was found along with a significant temperature correlation (R^2 value of 0.44 in Region 2 and 0.10 combined) and both are recommended as the basis of the polish value specification revision. In addition, the correlations obtained for all three objectives are shown in Figure 35.

The correlation for the 1 ¼ inch rubber pad and 3 7/8 inch travel path had an R^2 value of 0.75 with the following equation:

$$\boldsymbol{Predicted\ Skid\ Value\ (SN_{40R}) = 1.22 \cdot (BPN_{1.25''}) - 5.6}$$

SN_{40R} = measured skid number with a rib tire at 40 mph.

$BPN_{1.25''} = \ Average\ British\ Pendulum\ value\ after\ 4\ strikes\ with\ 1\frac{1}{4}\ inch\ slider\ pad.$

The correlation equation for a 3 inch pad width and 5 inch travel path had an R^2 value of 0.81 and consists of the following equation:

$$\boldsymbol{Predicted\ Skid\ Value\ (SN_{40R}) = 0.96 \cdot (BPN_{3''}) - 5.5}$$

SN_{40R} = measured skid number with a rib tire at 40 mph.

$BPN_{3''} = \ Average\ British\ Pendulum\ value\ after\ 4\ strikes\ with\ 3\ inch\ slider\ pad.$

The equations above represent the original objective of this research report. By using the above correlations between field and laboratory work, it is now possible to predict field skid number using the British Pendulum for select sites in Utah. It is also the equation the researchers were hoping to find when commencing this research project, as shown in Figure 35.

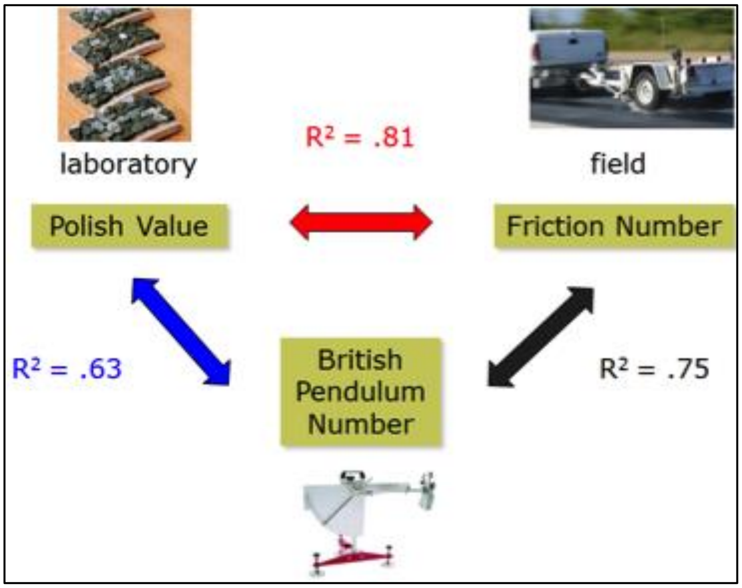

Figure 35 R^2 correlations for each objective.

The analysis and conclusions presented in this report are drawn from data collected through a broad and general approach. Additional study, construction, and monitoring of test sections are required to collect specific material property and performance data to validate the findings of this study.

6.0 RECOMMENDATIONS

6.1 Recommendations

Given the findings of this study, the researchers recommend that UDOT engineers adopt the revised variability-reducing laboratory friction testing techniques. These techniques include:

- using residual values when calculating BPN (as explained in section 3.2.1.1),
- establishing a strike path distance correlation between a curved and flat aggregate coupon to use in the field (as explained in section 3.2.1.5),
- randomly placing aggregate in coupons instead of hand selecting aggregate particles (as explained in section 3.2.1.2),
- implement race-track type field friction testing (as explained in section 3.2.1.3), and
- using 20-30 graded Ottawa sand in the fabrication of control coupons when using the accelerated polish test (as explained in section 2.3.1, ASTM E 303 and, AASHTO T-278).

It is recommended that the correlations obtained from this study be used as the basis of selecting target values for UDOT's friction management program. Specifically, it is now possible to select a polish value specification in line with the desired skid values as shown in Figure 27. For example, if a skid value of 45 is desired then a polish value specification of approximately 29 may be sufficient.

The findings of this study present evidence of a need to encompass design, material and construction variables and develop an order of priority in design procedures and specifications to satisfy the engineering and economic considerations. It should be noted that further confirmation of the findings will require construction and monitoring of test sections. The recommendations presented above are based on preliminary data collected over a two year period.

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APPENDIX A: Case Study Using Newly Created Correlation Equations

Recently there was an opportunity to use the above correlation equations to help UDOT engineers correlate the BPT skid friction value of a road surface to a skid value. UDOT's only skid trailer is in Florida for a total makeover to update the components and replace worn parts. During this time period without a trailer, a section of recently placed SMA along I-15 near Bountiful that had been profile ground and sealed with emulsion was reported to have a shiny appearance that concerned some of the traveling public. To appropriately investigate this occurrence and determine the friction values, the Region 1 materials engineer called upon the researchers to use the recently established correlation equations and provide assistance. To provide support the researchers took the same British Pendulum used in the research out to the field and tested six sections of the emulsion covered SMA along I-15 to determine the friction values. See Appendix 1 for the full report and case study that highlights the findings and shows how the research has provided practice ready information that can help UDOT in their friction management program and provide defendable and statistically accurate results of correlation when the skid trailer is either unavailable or unable to test due to inherent constraints.

Utah Department of Transportation
ATTN: L. Scott Nussbaum
1445 Wall Avenue
Ogden, UT 84404

November 10, 2015

RE: British Pendulum Pavement Friction Testing on SMA Grind Areas
SB I-15 HOV Lane at MP 319

Dear Mr. Nussbaum,

RABA KISTNER INFRASTRUCTURE, (RKI) is pleased to submit this report of our field testing for the above-referenced project. This study was performed in accordance with a UDOT request, dated November 6, 2015. The purpose of this study was to characterize field friction properties, perform British Pendulum Number (BPN) tests and estimate a correlation to a lock wheeled skid test. The following report presents the results of our field testing and material observations regarding the friction properties of the subject material.

Project Site

Based on conversations with you and Tom Roylance, we understand that throughout the Davis County I-15 Project there have been several sections of SMA with profile grinds that have been sealed with emulsion which appear shinier than usual. There have also been recommendations from UHP and others to look into the surface friction properties and see if there is a correlation between friction and the visual characteristics that have been observed. The pavement sections are located throughout the approximately 10 mile corridor in both the north and southbound lanes. Most SMA profile grinds consist of approximately 12 foot wide sections ranging in length from 30 to 50 feet. However, there are sections that are over 500 feet in length.

Field Study

To characterize the pavement friction, we completed a site visit on November 7, 2015. Six SMA grind locations ranging in length from 30 to 50 feet were tested with the British Pendulum Tester (BPT) in the outside wheel path according to ASTM E303-Standard Test Method for Measuring Surface Frictional Properties using the British Pendulum Tester. The six grind locations were found along the SB HOV lane at MP 319 just north of Parrish Lane. The BPT tests were run with a 3 inch rubber pad over a 5 inch travel path. In addition to the BPT tests, a Sand Patch (SP) test was also performed according to ASTM E965-Standard Test Method for Measuring Pavement Macrotexture Depth Using a Volumetric Technique. The SP tests were run approximately one foot south of each BPN test at location 4. In total, two SP tests and 18 BPT tests were performed along the HOV lane with the results shown in Table 1.

The conditions during testing were nighttime dusk with clear skies, cool temperatures and a slight breeze. The pavement temperature ranged from 34 to 40 degrees with an ambient temperature of approximately 35 degrees. The pavement surface at each test location was dry, clear of debris and representative of the test surface.

Pavement Condition

Five unique pavement types were evaluated within the six locations selected for evaluation. Two types were within the profile grinds while the other three consisted of existing pavements without profile grinds. The first pavement type was predominantly found in the left wheel path of the SMA grind and exhibited a shiny luster that was very smooth to the touch with emulsion typically filling up the entire groove height as shown in Figure 1. This surface type demonstrated the lowest friction values with an average BPN of 27.

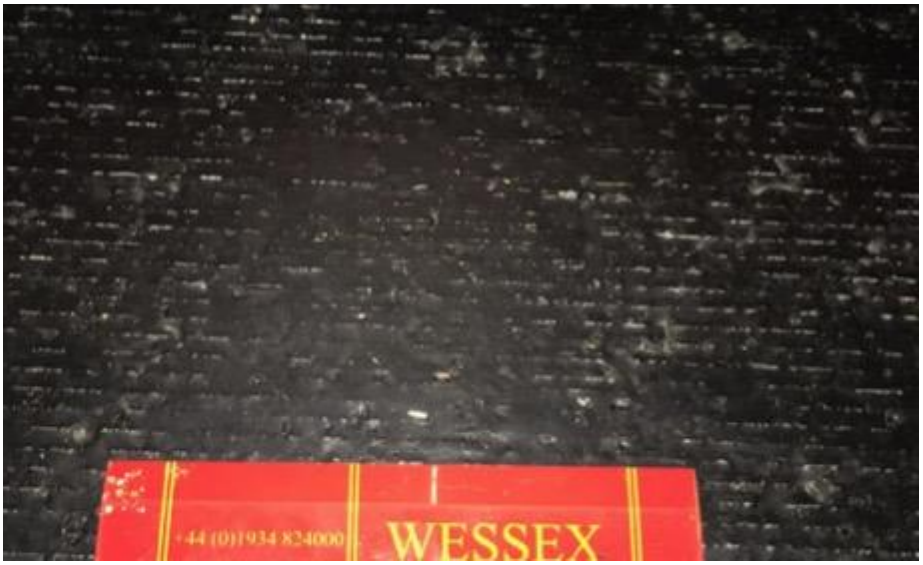

Figure 1 - SMA grind section with emulsion filling entire groove height.

The second pavement surface type was predominantly found in the right wheel path of the SMA grind and exhibited a moderately shiny luster that was moderately rough to the touch with emulsion typically filling up approximately half the groove height as shown in Figure 2. This surface type demonstrated the second lowest friction values but considerably higher than the first, with an average BPN of 53.

Figure 2 - SMA grind section with emulsion filling half of groove height.

The third pavement type consisted of existing SMA adjacent to the grind sections. Tests were performed in the left wheel path approximately 3 feet north of the grind sections. The existing SMA felt rough to the touch and was not shiny but had a dull look as shown in Figure 3. The binder appeared to be in the process of wearing off of the surface of the aggregates. This surface type had an average BPN of 59.

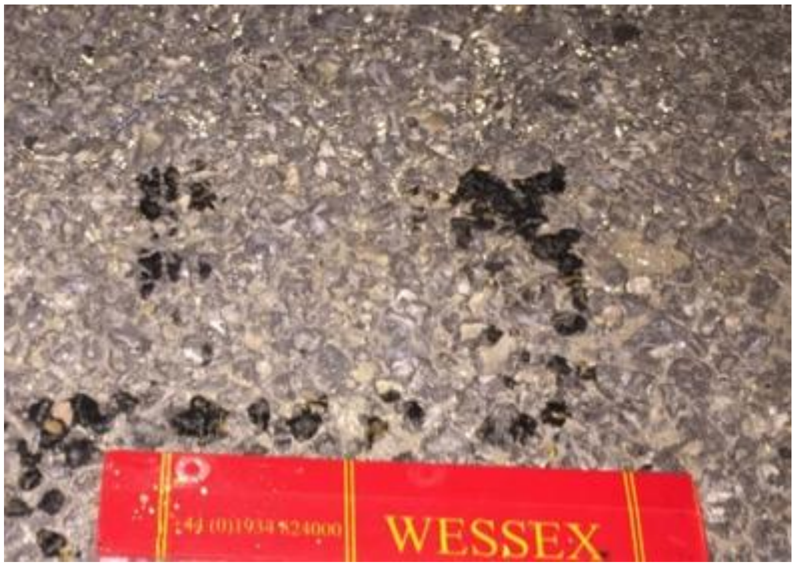

Figure 3 – Existing SMA adjacent to grind sections.

The final two pavement types consisted of the SMA shoulder and an adjacent concrete lane. The purpose of these two pavement types was to serve as a comparison only. The average BPN of the SMA shoulder was 82 while the average BPN of the concrete surface was 55. Sand patch tests were also performed in both the left and right wheel paths of the SMA grind sections and are shown in Figure 4.

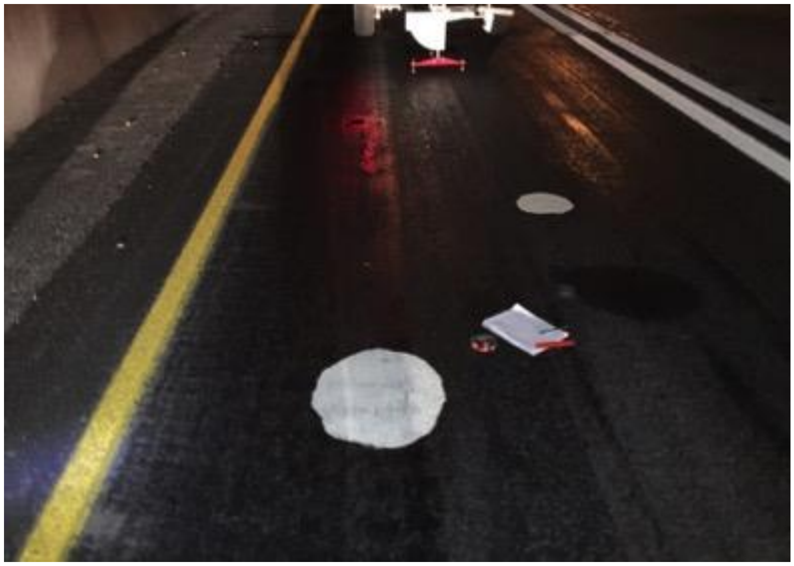

Figure 4 – Sand Patch testing in wheel paths

Table 1 – Summary of Friction Test Results.

Test #	Test Location	Pave Temp	Pavemet Type - Test Area	BPN	Skid Value*
1	1	40	SMA Grind - Left Wheel Path	33	26
2	1	36	SMA Grind - Right Wheel Path	47	40
3	1	35	SMA - Existing, No Grind, Left Wheel Path	60	52
4	1	35	SMA Shoulder outside of traffic lane	79	70
5	2	35	SMA Grind - Left Wheel Path	25	19
6	2	35	SMA Grind - Right Wheel Path	57	49
7	2	35	SMA - Existing, No Grind, Left Wheel Path	59	51
8	2	34	SMA Shoulder - Outside of Traffic Lane	85	76
9	3	34	SMA Grind - Left Wheel Path	24	18
10	3	34	SMA Grind - Right Wheel Path	55	47
11	3	34	SMA - Existing, No Grind, Left Wheel Path	59	51
12	4	35	SMA Grind - Left Wheel Path	23	17
13	4	35	SMA Grind - Right Wheel Path	50	43
14	4	35	Concrete - Left Wheel Path	55	47
15	5	38	SMA Grind - Left Wheel Path	28	21
16	5	35	SMA Grind - Right Wheel Path	57	49
17	6	35	SMA Grind - Left Wheel Path	26	20
18	6	35	SMA Grind - Right Wheel Path	54	46
			*Predicted value based on correlation equation.		

Table 2 – Averages of Uncorrected BPN Friction Test Results

Average Uncorrected BPN	
SMA Grind - Left Wheel Path	27
SMA Grind - Right Wheel Path	53
SMA - Existing, No Grind, Left Wheel Path	59
SMA Shoulder - Outside of Traffic Lane	82
Concrete - Left Wheel Path	55

Discussion

The average BPN results from Table 2 were entered into a correlation equation[1,2,3,4] which, based on laboratory and field testing, estimates the skid number (SN) values as would be predicted if the actual field ASTM E274 (Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire) test had been run. For example, in this report the average BPN value of 27 as measured in the left wheel path of SMA grind sections was correlated to a skid trailer using a ribbed tire at 40 mph (SN40R) skid value of approximately **20.** This correlation (approximately a 5 to 7 point drop from BPN to SN) is

consistent with a previous research study[1] and our experience in pavement friction testing and evaluation. Results for each pavement type and the associated skid value are shown in Table 3.

Table 3 – Summary of Average Predicted Skid Value Results

Predicted Skid Value (SN)	
SMA Grind - Left Wheel Path	20
SMA Grind - Right Wheel Path	46
SMA - Existing, No Grind, Left Wheel Path	52
SMA Shoulder - Outside of Traffic Lane	73
Concrete - Left Wheel Path	47

[1] Fu, Chien and Hua, Chen. "Alternate Polish Value and Soundness Specifications for Bituminous Coarse Aggregates." Texas Department of Transportation, Report No. 7-3994, Austin, TX, 1998, pg. 36.

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Comparing the two grind areas to the three non-grind areas it is evident that the friction decreases in each instance of a grind. The left wheel path of an SMA grind area is approximately 32 points lower than SMA without grinding. The right wheel path is approximately 6 points lower than the existing SMA.

The reduction in skid friction in the grind areas appears to be connected to the filling of the grooves with emulsion. This may be caused by one of two ways. Either the emulsion application rate was higher in the left wheel path and filled up the grooves or the groove height was shorter/ less defined while the application rate remained constant. As the emulsion fills up the groove it creates a layer of emulsion that overflows and covers the top of each ridge and prevents the pavement tire interaction from coming into contact with the natural micro-friction of the aggregates. In all six locations tested, the left wheel path was approximately 25 points lower than the right wheel path. Furthermore, the emulsion was visibly shinier and appeared to coat the surface ridges more completely in the left wheel path.

The diameter of the sand patch in the right wheel path was approximately 11.9 inches. The diameter of the sand patch in the left wheel path was approximately 19.2 inches. The area of the patch in the left wheel path was 2.6 times larger than the right wheel path. Therefore the low friction left wheel path had approximately 2.6 times less texture depth than the higher friction right wheel path.

Conclusion

Overall, the pavement friction is lower in areas that have had a profile grind when compared to areas without grinding. The biggest factor contributing to the low pavement is the emulsion filling up the surface grooves and covering the aggregate surface. Areas where emulsion appears to be the lightest have the highest friction. These areas were predominantly in the right wheel path.

The left wheel path consistently appeared to have more emulsion filling the surface grooves and covering the surface. In the worst case scenario the pavement friction in the left wheel path is approximately 32 points lower than the original SMA prior to grinding. There appears to be a correlation to the physical appearance or shininess and the friction, with the shinier pavement having less friction. Over time, as the emulsion is removed either by trafficking or other more aggressive measures, i.e. snow plows and intentional grinding, the surface friction should improve. The improvement is likely to increase to the friction value of the original SMA before grinding.

Recommendations

While recommendations are beyond the scope of this report we comment that the low friction pavement in the left wheel path of each grind section could possibly be improved by accelerating the removal of the emulsion coating. This may be accomplished by using a wire bristle broom type rotary sweeper or other device to grind off the slick emulsion from the surface and expose the aggregate surfaces with higher micro-friction.